

CASCADED USES OF THE GEOTHERMAL WATER AT THE UNIVERSITY OF ORADEA, ROMANIA

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ABSTRACT

The Oradea reservoir and the geothermal water well inside the University campus, as well as the current utilization of the geothermal water at the University of Oradea are briefly discussed in the first part of the paper.

A new building is at present under construction at the University campus and future developments are already planned and approved by the University Senate. The possibility to supply the total heat demand with the available geothermal water is considered and a new system is proposed for this purpose. The methodology used for the heat supply calculation is briefly presented, together with the results.

The paper shows the need for cascaded uses in order to increase the utilization efficiency and to improve the economics. It also shows the environmental advantages of geothermal energy utilization, as compared to the classic heating schemes currently used in Romania.

1. INTRODUCTION

The exploration for geothermal resources in Romania began in 1962. The drilling of over 200 wells was funded by the government as part of the Geological Research Program. All the reservoirs were assessed and their energy potential estimated. Assuming a reference temperature of 30°C the total power capacity was evaluated to be about 350 MW_t, of which only 130 MW_t are being utilized at present.

The largest known geothermal area in Romania is situated in the western region of the country and is part of the Pannonian Basin geothermal system. In all some 28 aquifers have been identified within an area of 2,500 km². These are confined aquifers with very small if any natural recharge, located in slightly consolidated Pliocene sand-stones at depths of between 800 and 2,100 m. The reservoirs are relatively small and the draw-down depends on the extracted amount of water. Diagrams presenting draw-down versus cumulative production during 12 to 14 years of exploitation show that on average the extraction of 3-5x10⁵ m³ of fluid from these reservoirs causes a pressure draw-down of 1 bar (Stefansson, 1988).

1.1 The Oradea geothermal field

The city of Oradea is situated in the western part of Romania. The reservoirs identified in the area are below and very different from those indicated above located in the Pannonian Basin. Three geothermal reservoirs have been identified within the city of Oradea and the surrounding area, known as the Oradea geothermal area. The reservoirs are usually named after towns or villages located in or close to the respective geothermal fields. The main reservoir is situated almost entirely within the city limits of the city of Oradea. It is hydrodynamically connected with a second one in the Felix Spa

Resort, about 10 km south-east from Oradea. The third one is near the village Bors, 6 km north-west from Oradea.

The Oradea reservoir is located in fractured Triassic limestone and dolomites 2,200 to 3,200 m deep. The extraction history shows that it is an open reservoir. In the last 15 years about 50 l/s have been withdrawn on continuous basis and no measurable drawdown encountered. Drawdown became significant only when the production rate was increased to 150 l/s. The reservoir temperature and pressure distribution indicate a hot water up flow between Oradea and Bors. The temperature in the Oradea reservoir decreases from NW towards SE in the Oradea aquifer and continues to decrease into the Cretaceous limestone Felix reservoir. In the Felix Spa Resort there are natural hot springs with temperatures between 35 and 50°C.

The chemical composition of the geothermal fluid in the Felix reservoir is the same as in Oradea. The concentration of total dissolved solids in the geothermal fluid is 1,000 ppm, mostly of calcium-sulfate-bicarbonate type. There are small quantities of dissolved non-condensable gases (up to 200 ppm) as CH₄, CO₂ and He. With the available technology it is not possible to recover the helium, due to its very high diffusivity. By the C14 method the water was found to be about 20,000 years old. The natural recharge originates in the Apuseni Mountains, about 80 km to the east of Oradea. More detailed information about the chemistry of the geothermal fluid from the Oradea area is available in the literature (Stefansson, 1988 and Rosca, 1993).

Of 12 boreholes that have been drilled into the Oradea reservoir, 11 are used as production wells and one for reinjection. The total installed capacity is at present 35 MW_t corresponding to a flow rate of 150 l/s of geothermal water at a mean temperature of 85°C. The production wells are currently discharged in artesian flow. The possibility to double the yield of the wells by pumping is considered a realistic estimate (Cohut, 1992). To increase the production rate to 300 l/s means that all the extracted water will have to be reinjected, not only to provide a pollution free disposal method, but also to sustain the reservoir pressure. Too great a pressure decline both in the Oradea and Felix reservoirs will eventually cause the natural hot springs there to dry up. New reservoir modeling is needed for an accurate evaluation of the production capacity.

1.2 The geothermal well at the University campus

Well no. 4796 was drilled in 1981 inside the University of Oradea as part of the National Geological Research Program. After an acid job it was used for production with artesian flow. The initial discharge tests confirmed a flow rate of 31 l/s of geothermal fluid with a well head temperature of 85°C and a dynamic pressure of 0.3 bar. At present, the maximum free flow rate available is 25 l/s and the well head temperature is 84°C.

The well has a 9⁵/₈" production casing down to 550 m, a 7" casing between 362-1,991 m and a liner from 1,888 m down to the bottom at 2,991 m. The liner is open (slotted) in the 2,000-2,914 m depth interval for production. All casings are cemented.

It is possible to install a 9" well pump (submersible or line shaft) down to a depth of 360 m, if necessary. New well tests and a fairly accurate reservoir model are needed to estimate the actual skin factor and the draw-down in the well. They will enable an accurate calculation of the setting depth and maximum flow rate for the well pump. Based on the available data, the maximum flow rate is estimated at 50 l/s and the well head temperature at 87°C, as the temperature at the depth of 2,000 m is 93°C (Cohut, personal communication).

will be finished by 1995. The University Senate also approved other new developments, such as:

- a library;
- three student hostels (1,000 places);
- a phizio-kineto-therapy facility;
- a swimming pool with geothermal water;
- a tropical greenhouse (for training in horticulture).

The layout of the proposed system for cascaded uses of the geothermal water is shown in Figure 1

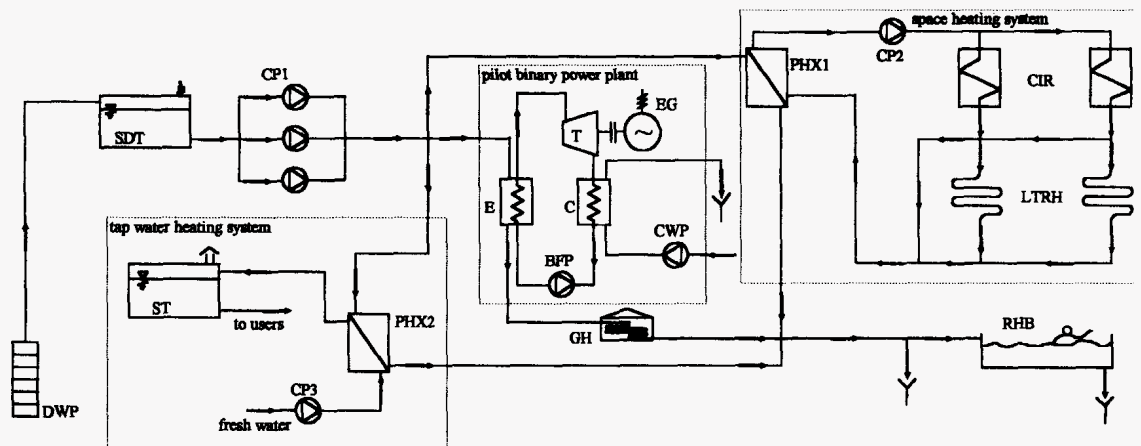


Figure 1: Layout of the cascaded uses of the geothermal water at the University of Oradea

13 The current geothermal energy utilization and proposed developments

The geothermal heating system at the University of Oradea was set on line in 1981. It provides domestic hot water and space heating for the University campus and for three apartment blocks located in the vicinity. The University campus comprises three buildings with class rooms, laboratories and offices, one building with laboratories and workshops, two buildings for the National Geothermal Research Institute, two hostels accommodating about 650 students, a canteen, two gymnasiums, a small greenhouse and a number of smaller ancillary buildings. The total area of the University campus is about 145,000 m².

The National Geothermal Research Institute designed and developed a pilot binary cycle power plant using carbon dioxide (CO₂) as working fluid. The first installation used a piston engine for the working fluid expansion and produced 1 MW electric power. A new pilot power plant has now been designed, the piston engine being replaced by a turbine. Both are experimental installations and therefore used for testing usually during the warm period of the year, when more geothermal water is available for the evaporator.

The geothermal water is piped to the heating station located about 400 m from the well. The thermal energy is transferred to the space heating water and to the fresh water in shell and tube heat exchangers. In 1994 these were replaced by new stainless steel plate heat exchangers (made in Romania). The geothermal water flow rate through the heat exchangers is regulated by orifices and, for the space heating water, also by regulation valves. At present, the entire control and regulation is done manually.

The room heaters used at the University of Oradea are, as usual in Romania, standard cast iron radiators. The number of elements for each room is determined as a function of the room volume or, for buildings of standard ceiling height, as a function of the floor area of the room. The standard indoor design temperature is 18°C. The incidental heat gains from external sources, such as solar radiation and human activities (cooking, washing, body heat), increase the indoor temperature usually to about 20°C. The standard domestic hot water temperature is 65°C. For these conditions, the maximum thermal power demand of the heating system is about 3.4 MW_t. The existing heating system can be developed to supply the total heat demand in the future, considering that all the planned objectives will be attained. A new building is already under construction and

The geothermal water is pumped by the deep well pump (DWP) to the storage and degassing tank (SDT) through a surface steel pipe insulated with rock wool and protected by aluminum sheet. It is recommended to equip the DWP with a frequency regulator. To avoid corrosion, the pressure in the SDT is higher than the atmospheric pressure, as to prevent oxygen from entering into the water. This also avoids calcite scaling by keeping part of the carbon dioxide in solution. From the SDT the geothermal water is fed by a group of circulation pumps (CP1) to the binary power plant and to the space heating and tap water heating systems. Three pumps are envisaged for the CP1 group, out of which one to be supplied with a frequency regulator, thus having the possibility to operate it at partial loads, to deliver any required flow rate to the users.

The geothermal water outflow temperature from the binary power plant evaporator (E) is about 45-50°C. This temperature level is suitable for heating the greenhouse at partial loads, when the outdoor temperature is sufficiently high to turn off the space heating system and more geothermal water is available for the binary power plant. The cooling fluid for the condenser (C) is fresh water produced by a shallow well.

The stainless steel plate heat exchanger (PHX1) transfers the heat from the geothermal water to the space heating water. The circulation pump (CP2) feeds the space heating water firstly to the buildings with cast iron radiators (CIR). The outlet flow from these buildings is used for heating the buildings with low temperature room heaters (LTRH) or can return directly to PHX1.

The fresh water from the municipal network is heated in the stainless steel plate heat exchanger (PHX2). The hot tap water is pumped by the circulation pump (CP3) to the storage tank (ST) located on top of the highest building. From the ST the hot tap water is distributed to users by gravitational circulation. The ST volume is calculated to compensate the daily variations in demand, so that the CP3 will operate at full load continuously.

The geothermal water outflow from all the utilizations presented above is used for recreational and health bathing (RHB) in outdoor swimming pools and the indoor phisio-kineto-therapy facility. The spent geothermal water is discharged into a small river running just outside the University campus. The geothermal water from the Oradea reservoir does not contain toxic or polluting chemicals and the river is fed by a natural geothermal spring, so that the surface disposal has no adverse environmental effects.

2. TECHNICAL CALCULATIONS

The technical calculations presented in this paper generally follow the guidelines developed by Harrison et al. (1990) and Piatti et al. (1992) for the Commission of the European Communities.

The thermal power demand for a constant indoor temperature is a function of the outdoor air temperature and the wind velocity. The design outdoor air temperature for the Oradea area is -7°C . Slightly lower temperatures are occasionally encountered (down to -12°C) but, as Karlsson (1984) has demonstrated, it is neither economic nor necessary to design the heating system for the minimum measured outdoor temperature because the heat stored in walls, floor, ceiling, furniture etc. tends to level off the indoor temperature variation for short periods of time (up to three days). The temperature demand intensity (T_d) is defined as the difference between the planned indoor and actual outdoor temperatures. For the conditions stated above, the maximum temperature demand intensity is 25°C .

To calculate the annual heat requirements of a single user or group of users and also the power input from different sources for every temperature demand intensity it is necessary to know the variation of the total heat rate (or thermal power) demand over the year. The usual method is to determine first the variation of the temperature demand intensity with time during one year. For this purpose, recorded meteorological data is used. The average number of days during which certain values of temperature demand intensity occur is calculated. A histogram is then plotted in which the decreasing values of temperature demand intensity (usually in steps of 1°C) are plotted versus cumulated number of days. As the room temperature demand is constant, the histogram is converted into a curve showing the duration of the temperature demand intensity. This diagram for the Oradea area is given in Figure 2. Usually the central heating systems in Romania are turned off when the daily mean temperature of the outside air is above 10°C for three days in a row. Following this procedure, the average heating season for the Oradea area is 172 days and the minimum T_d encountered 5°C .

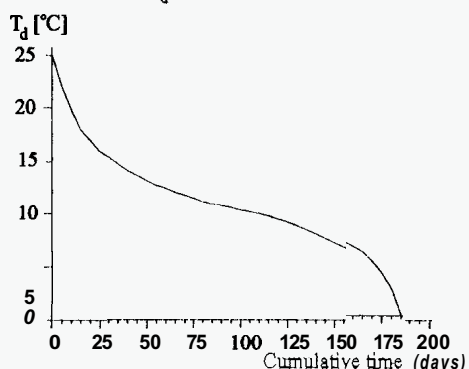


Figure 2: Temperature demand intensity duration curve for the Oradea area

The thermal power transferred from the radiator to the air inside the room has to be equal to the thermal power transferred from the indoor to the outdoor air. This can be calculated as:

$$P_t = V \cdot G \cdot T_d \quad (1)$$

where:

P_t	[W]	= thermal power (heat rate);
V	[m ³]	= total air volume;
G	[W/m ³ ·°C]	= volumetric heat loss coefficient;
T_d	[°C]	= temperature demand intensity.

The volumetric heat loss coefficient is a building constant and depends on materials and thickness of walls, existence and type of thermal insulation etc. Part of the existing buildings are rather old, having very thick brick walls. The total heated volume of these old buildings is about 69,000 m³ and the respective volumetric heat loss coefficient is estimated as $0.7 \text{ W/m}^3 \cdot ^{\circ}\text{C}$. The newer existing buildings, with a total volume of about 57,000 m³ and the ones to be built in the future, with a total volume of about 80,000 m³, are all with compound wall made of reinforced concrete, bricks and expanded concrete panels. The volumetric heat loss coefficient for these buildings was estimated as $1 \text{ W/m}^3 \cdot ^{\circ}\text{C}$. For the conditions

stated above, the calculated maximum thermal power demand of the space heating system for the existing buildings and the new developments are respectively:

$$\begin{aligned} P_{n \max \text{ EB}} &= 3,125 \text{ kW}; \\ P_{n \max \text{ ND}} &= 1,975 \text{ kW}. \end{aligned}$$

In Romania the thermal power supply is regulated by modifying the inflow temperature of the heating fluid into the radiators while keeping the mass flow rate constant. For the temperature range the room heaters are working in, both the inflow and outflow water temperatures can be approximated as linear functions of the temperature demand intensity. The total radiator area of the existing buildings is about 5,630 m² and these can supply the heat demand for inflow/outflow water temperatures of $80/50^{\circ}\text{C}$. This outflow temperature suits various types of low temperature room heaters, i.e. floor, wall and/or ceiling heating. To use the total outlet from the existing buildings for the new developments, these will be designed for inflow/outflow water temperatures of $50/30^{\circ}\text{C}$. The temperature characteristics of both types room heaters of are shown in Figure 3.

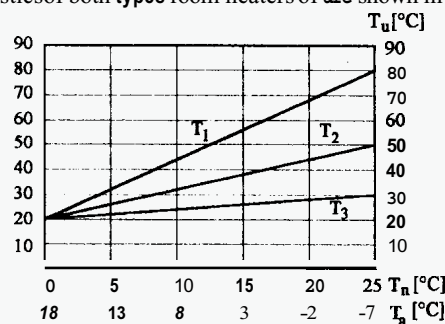


Figure 3: Temperature characteristics of linearly regulated room heaters

The notations used in Figure 3 are:

T_a	-outdoor (atmosphere) air temperature;
T_d	-temperature demand intensity;
T_1	-cast iron radiator water inflow temperature;
T_2	-cast iron radiator outflow and low temperature heaters inflow temperature;
T_3	-low temperature heaters outflow water temperature.

The average daily consumption of domestic hot water per capita is 100 l. At the University of Oradea heating station the total demand is about 200 m³/day, including the domestic hot water delivered to the neighboring apartment blocks and the water for cooking, washing, laundry etc. (excluding the geothermal water for health bathing). The fresh water temperature and the standard temperature for domestic hot water in Romania are, respectively:

$$\begin{aligned} T_f &= 15^{\circ}\text{C} = \text{temperature of fresh water (cold);} \\ T_{hw} &= 65^{\circ}\text{C} = \text{standard temperature of domestic hot water.} \end{aligned}$$

The heat capacity of the mass flow rate is defined as the product of the mass flow rate and its specific heat (assumed as constant):

$$M = f \cdot \gamma \quad (2)$$

where:

M	[W/°C]	= heat capacity of the mass flow rate;
f	[kg/s]	= mass flow rate;
γ	[J/kg·°C]	= heat capacity (mean value).

The thermal power required for heating the tap water is therefore:

$$P_w = M_w \cdot (T_{cw} - T_{hw}) \quad (3)$$

and the calculated values for the total consumption expected for the future are, respectively:

$$\begin{aligned} M_w &= 10.5 \text{ kW/}^{\circ}\text{C}; \\ P_w &= 500 \text{ kW} \end{aligned}$$

The heat capacity of the mass flow rate in the network for space heating is calculated, according to Equation 4, as the ratio between the maximum thermal power demand and the temperature drop in the room heaters.

$$M_n = \frac{P_{n \max}}{T_i - T_o} \quad (4)$$

where:

$P_{n\max}$ [kW] = maximum thermal power demand of the space heating network;
 T_i [°C] = room heater water inflow temperature;
 T_o [°C] = room heater water outflow temperature.

For the conditions stated above, the heat capacity of the mass flow rate is almost **equal** for both the cast iron radiators and low temperature room heaters, the calculated values being:

$M_{nEB} = 104.2 \text{ kW/}^\circ\text{C}$;
 $M_{nND} = 98.75 \text{ kW/}^\circ\text{C}$.

It is further assumed that both plate heat exchangers PHX1 and PHX2 in Figure 1 are used in counter flow. The equations for this type of heat exchangers are identical to those used for common counter flow shell and tube heat exchangers. With these initial assumptions the equations required to calculate the heat exchange area are relatively simple, as presented below. The heat transfer rate, or thermal power, (P_{HX}) of a heat exchanger is:

$$P_{HX} = M_h \cdot (T_{hi} - T_{ho}) = M_c \cdot (T_{ci} - T_{co}) = A \cdot U \cdot \text{LMTD} = E_x \cdot M_s \cdot (T_{hi} - T_{co}) \quad (5)$$

where:

M_h [W/°C] = heat capacity of the hot fluid flow rate;
 M_c [W/°C] = heat capacity of the cold fluid flow rate;
 M_s [W/°C] = smaller heat capacity of the two flow rates;
 T_{hi} [°C] = inlet temperature of the hot fluid;
 T_{ho} [°C] = outlet temperature of the hot fluid;
 T_{ci} [°C] = inlet temperature of the cold fluid;
 T_{co} [°C] = outlet temperature of the cold fluid;
 LMTD [°C] = logarithmic mean temperature difference;
 U [W/m²·°C] = overall heat transfer coefficient;
 A [m²] = area of the heat exchange surface;
 E_x [-] = heat exchanger effectiveness.

The logarithmic mean temperature difference (LMTD) between the hot and cold fluids across the total heat transfer surface of a counter flow heat exchanger is defined as:

$$\text{LMTD} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln(T_{hi} - T_{co}) - \ln(T_{ho} - T_{ci})} \quad (6)$$

The effectiveness of the counter flow heat exchangers is given by:

$$E_x = \frac{1 - e^{-N(1-R)}}{1 - R \cdot e^{-N(1-R)}} \quad (7)$$

where:

R [-] = the ratio of the smaller to the larger heat capacities of the flow rates;
 N [-] = the number of heat transfer units, given by:

$$N = \frac{U \cdot A}{M_s} \quad (8)$$

The calculated values of the plate heat exchangers area for the space heating system (A_{PHX1}) and the tap water heating system (A_{PHX2}) are, respectively:

$A_{PHX1} = 28.6 \text{ m}^2$;
 $A_{PHX2} = 548 \text{ m}^2$.

The heat supply calculation for the space heating system was carried out for full load and some specific partial loads. The results are presented in Table 1

Table 1: Heat supply calculation results

Parameter	20	40	60	80	100
T_d [°C]	5	10	15	20	25
T_a [°C]	13	8	3	-2	-7
T_1 [°C]	32	44	56	68	80
T_2 [°C]	27	32	38	44	50
T_3 [°C]	22	24	26	28	30
T_{co} [°C]	27	29	31	33	35
f_g [kg/s]	4.15	8.59	13.33	18.43	23.93
P_n [kW]	1,042	2,084	3,120	4,168	5,100

The calculated values for geothermal water mass flow rate (f_{gWH}), annual geothermal water consumption (m_{gWH}) and energy used for tap water heating (E_{WH}) and annual geothermal water consumption (m_{gSH}) and energy used for space heating (E_{SH}) are, respectively:

$f_{gWH} = 1.87 \text{ kg/s}$
 $m_{gWH} = 58,872 \text{ m}^3$;
 $E_{WH} = 28,804.103 \text{ GJ}$;
 $m_{gSH} = 167,885 \text{ m}^3$;
 $E_{SH} = 35.78.103 \text{ GJ}$.

3. CONCLUSIONS

The maximum geothermal water flow rate necessary for space and tap water heating is about 27 kg/s. It should be noticed that this flow rate will be only used for short periods of time, at the maximum temperature demand intensity. The maximum flow rate available by well pumping is, on the other hand, about 50 l/s. It is possible to use the available geothermal water from the well at the University of Oradea campus for all envisaged future developments. With the maximum flow rate available by well pumping it will be possible to develop the heating system to supply other users, i.e. the military camps located near the campus and not connected to the municipal district heating system. The municipal district heating network is rather far from the University campus and the price of thermal energy is high. The University of Oradea being state owned, all expenses are paid by the Ministry of Science and Education from the State Budget. For the above reasons, the economic feasibility of cascaded uses is not addressed herein. It is, anyhow, obvious that the geothermal energy utilization has not only economical, but also environmental advantages.

The annual energy savings by using the geothermal energy only for tap water heating and space heating will be about 64.6 10³ GJ, corresponding to an annual fuel saving of about 7,720 tones coal equivalent. The annual amount of CO₂ released into the atmosphere from the geothermal water used for space heating and tap water heating, compared to the amount released by a coal fired power plant to produce the same thermal energy, is shown in Table 2. The calculation was carried out for a perfect combustion of coal with 60% Carbon (C) and a Low Calorific Value of 8,370 kJ/kg. The flue gasses from the power plant also comprise solid particles and toxic gasses such as sulfur dioxide (SO₂) and nitrogen oxides (NO_x). Power plants fired by low grade coal, as those in Oradea City, also produce large quantities of ash, which requires expensive disposal means.

Geothermal	Coal Fired Power Plant				
CO ₂	CO ₂	SO ₂	NO _x	Ash	Particles
35.64	24,086	134.4	139.00	2,190	15.84

REFERENCES

- Cohut, I. (1992). *Current Status and Prospects of the Romanian Geothermal Industry*. Report presented at the International Seminar on Geothermal Energy, Oradea, Romania, 5 pp.
- Harrison, R., Mortimer, N. D., and Smarason O. B. (1990). *Geothermal Heating: A Handbook of Engineering Economics*. Pergamon Press, Oxford, U. K., 558 pp.
- Karlsson, T. (1984). *Geothermal district heating. The Icelandic experience*. UNU Geothermal Training Programme, Orkustofnun, Reykjavik, Iceland, Report 4, 116 pp.
- Piatti, A., Piemonte, C., and Szegő, E. (1992). *Planning of Geothermal District Heating Systems*. Kluwer Academic Publishers, Dordrecht, The Netherlands, 308 pp.
- Rosca, M. (1993). *Economical and Technical Assessment of some Geothermal Development Scenarios for Oradea, Romania* UNU Geothermal Training Programme, Reykjavik, Iceland, Rep. 13, 44pp.
- Stefansson, V. (1988). *Research and Utilization of Geothermal Resources. Phase II*. Report to the United Nations on the mission Rom-82-005, United Nations, New York, USA, 76 pp.